

ACTIVE CAPTURE OF LOW-ENERGY VOLATILES: BRINGING BACK GASES FROM A COMETARY ENCOUNTER,

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One of the fundamental problems with sample return missions to volatile-rich objects in the solar system is how to bring back samples of the volatiles. This problem is particularly severe when the mission is a cometary coma fly-through, for two reasons. First, since the fly-by will be in the molecular flow, not viscous flow, regime, the abundance of volatiles encountered is fixed by the column density times the *cross-sectional* area of the collector (not total surface area). This effectively eliminates any advantage offered by collectors that depend upon enhanced surface area for their effectiveness, such as activated charcoal or zeolite. Moreover, adsorptive type of collector would be rendered completely useless by overwhelming quantities of terrestrial volatiles unless extraordinary measures were taken to prevent both pre-mission and post-mission exposure to the terrestrial environment. For instance the total column density of 3×10^{15} water molecules/cm² predicted for the STARDUST mission, which will fly through the coma of Wild 2 in 2004, would be encountered in less than a millimeter of normal atmosphere. Second, the encounter velocity, typically a few km/s (for STARDUST it is 6 km/s, about 0.15 eV/amu), is too high for thermalization (and hence surface area collection) but too low for implantation (insufficient energy for significant lattice disruption or deformation). Is the trapping of volatiles an impossible task for a cometary encounter mission? This is the question we asked ourselves when we set out to explore the possibilities for a volatiles collector for the STARDUST mission.

It has been well-established and convincingly demonstrated by the Apollo Solar Wind Experiment [1] that atoms can be implanted into aluminum foil at solar wind energies (1 KeV/amu) with near unity efficiency and they are stable against loss. Implantation into evaporated aluminum films show similar stability, which have the additional advantage that release of the captured atoms can be done with laser volatilization of only the thin (few thousand Angstroms) films [2], greatly reducing any associated blank. However, implantation at an encounter energy of about 0.15 eV/amu does not occur. Although, there is some evidence that low-energy (50-500 eV) capture does occur at some level [3], retention of the captured ions is a problem. Moreover, cometary volatiles will be encountered at energies below any of the previous studies, (about 0.15 eV/amu). The only hope appeared to be an active volatiles collector that covers over any atoms adsorbed onto the surface during their surface adsorption time, kind of like the way ion pumps capture noble gases. Available data for adsorption onto cold surfaces, extrapolated to the expected substrate temperature of about -50°C, however, made the task appear hopeless, predicting retention times of 10^{-8} seconds, far too short for capture by film deposition. There is some evidence that fresh films deposited in a vacuum contain chemically-active sites and acquire surface atoms by processes more effective than Van der Waals forces, referred to as “anomalous adsorption

of Xe” [4]. If this, or another process less important at the lower temperatures (rendering the extrapolation, referred to above, from existing data inappropriate), capture of cometary volatiles in a co-deposited metal film might be possible after all.

The first experiments on low-energy capture were made with an ion source removed from a quadrupole mass spectrometer, capable of providing a stable beam in the correct energy range (5-100 eV), and a conventional evaporation basket. Sapphire collector substrates were mounted on an electrometer so that the beam current could be monitored. Evaporation of a low-Z metal (Al or Mg) onto the substrate was done simultaneously with the arrival of a low energy (15 eV for Kr) beam. The collected gases were released from the evaporated metal film by laser volatilization and measured in a conventional mass spectrometer. Measurements were made with Ar, Kr and Xe, and with Mg, Al and Zn as the coating film. Film thicknesses were typically a few thousand Angstroms with deposition rates 5 - 50 Å/sec. It is believed that species residing on the surface will be covered by the metal film and retained indefinitely. An initial guess at the expected capture efficiency would therefore be the surface dwell time (a function of the species and the temperature, less than 10^{-8} sec at room temperature for Kr) divided by the time for deposition of a monolayer of metal (say 10^{-2} sec). This yields an expected capture efficiency of less than 10^{-6} for Kr at room temperature.

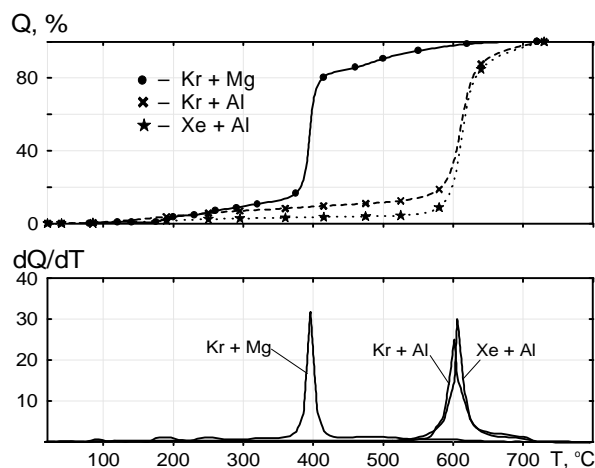


Fig. 1. Cumulative and differential gas release patterns for Mg and Al films co-deposited onto a sapphire substrate with the simultaneous impingement of low energy Xe and Kr ions (~ 0.15 eV/amu). Al and Mg melt at nearly the same temperature, but Mg sublimates at about 400 °C.

Actual capture efficiencies, the measured ratio of gas retained to gas impinging on the substrate, are considerably higher than this, between 0.1 and 1 percent for Ar, Kr and Xe with Ar at the low end. These measured capture effi

ciencies suggest that the actual surface residence times are not strictly determined by Van der Waals forces (adsorption), but must involve other mechanisms. Among the candidates are "anomalous adsorption" and forward scattering into the lattice, both of which can enhance surface residence times and capture probability. Regardless of the mechanism, extended surface dwell times allow co-deposited metal films to cover and retain a significant fraction of the impinging volatiles, making the active collection of volatiles a viable component of comet sample return missions. Gases trapped in the metal films are stable for long-term storage and released only upon the melting of Al films or sublimation of Mg films (Fig 1).

Capture of volatiles by the co-deposition of thin metal films has two great advantages: The first is the capture process itself whereby a visiting molecule (whether by forward scattering or tunneling into the lattice or by anomalous adsorption on the fresh surface) becomes tightly bound in a deposited metal matrix. An extensive amount of data has shown that noble gases are retained indefinitely in this thin metal film until released by a single (10 ns) pulse from a Nd-YAG laser delivering $\sim 1.5 \text{ J/cm}^2$ [2]. A second advantage is that only the film itself is affected during the subsequent laser ablation to remove the film and liberate the trapped volatiles. This, of course, greatly reduces the background and increases the analytical precision. Comparisons between the total gas released during step-wise heating with that liberated by laser ablation of the surface film shows

that all of the captured volatiles can be quantitatively recovered. The Active Volatiles Collector developed for the STARDUST mission is a low mass ($< 500\text{g}$), low power ($< 15 \text{ watts}$) device which operates only for five minutes during comet encounter, evaporating a Mg film onto sapphire substrate. By substituting diamond substrates for some of the sapphire at the ends of the collector (where only $\sim 200 \text{ \AA}$ of Mg are deposited) it should be possible, using IR transmission spectroscopy, to measure molecular species, such as CO , CO_2 , NH_3 , CH_3OH , etc. The only difficult part of an autonomously operated experiment is control of the evaporation rate. This is accomplished by evaporating Mg from a thin tantalum wire that has been sputter-coated with Mg. Since Mg sublimates at about 450°C , with a vapor pressure that is a steep function of temperature, control of the power delivered to the wire to less than a percent is required. This is done by multiplying the delivered voltage and current (using a current-sense resistor) in an analogue multiplier the output of which (the power) is used as the control signal for the power supply driving the evaporator wire.

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